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Education

Comparison of learning outcomes for teaching focused cardiac ultrasound to physicians: A supervised human model course versus an eLearning guided self- directed simulator course

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A R T I C L E   I N F O

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A B S T R A C T

Purpose: Focused cardiac ultrasound (FCU) training in critical care is restricted by availability of instructors. Supervised training may be substituted by self-directed learning with an ultrasound simulator guided by automated electronic learning, enabling scalability.
Materials and methods: We prospectively compared learning outcomes in novice critical care physicians after completion of a supervised one-and-a-half-day workshop model with a self-guided course utilizing a simulator over four weeks. Both groups had identical pre-workshop on-line learning (20h). Image quality scores were compared using FCU performed on humans without pathology. Interpretive knowledge was compared using 20MCQ tests.
Results: Of 161 eligible, 145 participants consented. Total Image quality scores were higher in the Simulator group (95.2% vs. 66.0%, $P < .001$) and also higher for each view (all $P < .001$). Interpretive knowledge was not different before (78.6% vs. 79.0%) and after practical training (74.7% vs. 76.1%) and at 3 months (81.0% vs. 77.0%, all $P > .1$). Including purchase of the simulator and ultrasound equipment, the simulator course required lower direct costs (AUD$796 vs. $1724 per participant) and instructor time (0.5 vs.1.5 days) but similar participant time (2.8 vs. 3.0 days).
Conclusions: Self-directed learning with ultrasound simulators may be a scalable alternative to conventional supervised teaching with human models.

1. Introduction

Physician-performed focused cardiac ultrasound (FCU) is established in anesthesiology and critical practice [1,2]. The most important barrier to adoption reported by Conlin et al. [1] was lack of training opportunity, who identified a strong need for a scalable teaching process that provides acceptable learning outcomes.

There are three key components to learning a new skill such as FCU – knowledge, practical learning and practice. The traditional initial training model for FCU is a combination of initial knowledge teaching (lectures or eLearning) followed by a supervised workshop of ultrasound on healthy human volunteers. Unfortunately, the initial practical training is dependent on close supervision by trainers, which significantly limits the upward scalability of FCU teaching programs to cope with the increasing demand.

Ultrasound simulators have evolved to be highly sophisticated and realistic, with a recently developed advantage of showing pathology during the initial learning phase, enabling both learning of image acquisition as well as interpretation and reporting. Simulators have been demonstrated to be effective in substitution of human volunteers in initial learning of acquisition of normal FCU views [3], but expansion in

Abbreviations: FCU, Focused Cardiac Ultrasound; TTE, Transthoracic echocardiography; LV, Left ventricular; RV, Right ventricular; MCQ, Multiple choice question; SD, Standard deviation.

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training is still restricted by the use of instructors for supervision and also of teaching interpretation of pathology.

The University of Melbourne has developed a course that uses a simulator (Vimedix™, CAE Healthcare, Montreal, Canada) that displays pathology to be almost entirely self-directed (FCU TTE Course [4]), reducing the restriction of trainers to expand the teaching FCU. The supervised teaching of acquisition of normal views is reduced to 3-h using a simulator, after which training of acquiring normal views and interpretation of pathology is entirely self-directed practice with the simulators. By reducing the dependence of training on instructors, the simulator course is much more efficient, enabling an increased volume of training. The evidence gap is whether the learning outcomes of the simulator course are as good as the supervised human model. The aim of this study was to compare the simulator-based training course to a traditional model of a supervised workshop with human models for image acquisition and interpretive skills.

2. Materials and methods

This prospective observational non-randomized comparative study was approved by The University of Melbourne Human Research Ethics Committee (144321) prior to the commencement of the study period. Written consent was obtained from all participants.

At the commencement of the study period, participants enrolled in either the traditional human model methods course (iHeartScan™ course [5]) or the self-directed simulator course (FCU TTE course [4]) were invited to participate in the study. It was not feasible to randomize participants to the two courses due to availability of participants to the course dates. Exclusion criteria included inability to return for follow up assessment (for example participants from another state or country). There was no other restriction to the amount of previous training in FCU, however participants were requested to declare any training in FCU prior to the course.

Both courses are aimed at initial learning to perform and interpret FCU for a range of cardiac pathology and abnormal hemodynamic states commonly encountered in the perioperative and critical care setting. Both courses provided instruction of the iHeartScan™ protocol [6], which has been validated to be feasible and able to discriminate between significant and non-significant structural cardiac pathology in the perioperative and critical care settings [7-10]. Interpretation of pathology uses pattern recognition of two-dimensional and color flow Doppler images, to identify clinically important cardiac pathology, defined as: either left ventricular (LV) systolic or diastolic dysfunction, right ventricular (RV) systolic dysfunction, moderate or severe valve stenosis or regurgitation [11,12], or pericardial effusion of >0.5 cm. Left ventricular systolic dysfunction is defined as systolic fractional reduction in LV internal dimension <28% or a reduction in LV end diastolic area <50%. Left ventricular diastolic dysfunction is defined as normal LV systolic function with raised left atrial pressure determined by the presence of a fixed curvature of the interatrial septum towards the right atrium, as demonstrated by Haji et al. [13] Right ventricular dysfunction is defined using ultrasound as dilation of the RV end-diastolic area to greater than two-thirds of the LV end-diastolic area and reduced RV free wall motion with or without flattening of the interventricular septum. Hemodynamic state is assessed with ultrasound by categorization into normal, empty, vasodilated, LV systolic and/or diastolic failure, or RV failure, as described previously [14] using the assessment of LV and RV volume and contractility, and movement and position of the interatrial septum. Clinically insignificant findings include mild valvular stenosis or regurgitation, or mild reduction in systolic ventricular function.

Both courses use the same pre-workshop delivery of knowledge base, which is entirely provided by the internet (eLearning), which includes five tutorials and review of 20 FCU cases of pathology, assessed by five multiple-choice questions (MCQ's) per case study (total of 100 MCQ). The difference between courses is in the delivery of the practical learning (Table 1), being either supervised scanning of healthy human models over a 1.5 day workshop, (Fig. 1A) or by self-directed directed practice with simulators (Fig. 1B and C) over a four-week period. Simulator group participants initially attended an 3-h proctored session (Fig. 1B) where they are shown how to operate the simulator and complete the ten case pathology practice on their own over the following four weeks. They are also given brief tuition and practice on how to perform the FCU examination using the simulator. This represents a significant change in the delivery of the practical skill teaching, from a fully proctored 1 and a half day workshop to a 3-h workshop aimed at teaching the participants how to teach themselves using the simulator, which is performed at repetitive intervals spaced over the four weeks at the convenience of the participants. The simulator provides an alternative model to practice FCU (healthy human volunteers) that does not require supervision with an instructor, as well as the opportunity to practice acquiring and interpreting pathology. Another advantage of the simulator over the alternative course is that the simulator allows participants to relate the standard 2-dimensional ultrasound image to the 3-dimensional anatomy construct that is shown on the left screen of the simulator (Fig. 1 Bi).

The self-directed practice on the simulators uses a case study structure (Fig. 1C) for at least 10 pathology cases (Fig. 1 Ci), which are delivered through the eLearning platform (Figure 1Cii). In brief, the participant opens a case study through their eLearning portal and reads the scenario. They are then instructed to open a pathology case on the simulator and conduct a FCU examination. They then complete an iHeartScan report (Figure 1Ciii) [6] and answer 5 MCQ questions related to the case. Upon submission of the answers to the MCQ's through the eLearning portal, they are automatically marked, and explanations provided for incorrect responses. Participants are given the opportunity to re-attempt the MCQ's if less then 4 out of 5 MCQ's were correct, after which they are provided with a model answer report, from which they are asked to compare their report to. The participants are also provided with a case summary, commenting on the key learning points provided by the pathology example. This process provides real-time assessment and feedback of their image acquisition, interpretation, reporting and retention and integration of knowledge base. This interactive learning experience during the practice case phase of the simulator course is a little different to the traditional human model methods course, where the participants review ultrasound images of real pathology in a group moderated by an instructor, rather than obtaining the images of

Table 1
Educational components of the simulator and human model focused cardiac ultrasound courses. MCQ; multiple choice question exam.

Component	Simulator model	Human model
Pre-workshop knowledge-base learning	Five tutorials 20 on-line FCU pathology cases	Five tutorials 20 on-line FCU pathology cases
Duration	1.5 days	1.5 days
Assessment	100 MCQ	100 MCQ
Practical learning		
Mode of learning	Ultrasound simulator with pathology cases	Ultrasound machines and healthy human volunteers
Instructor: participant ratio	1:5	1:5
Workshop	0.25 days	1.5 days
Post workshop learning	unsupervised practice on simulator guided by eLearning course	none
Duration	0.75 days (over 4 weeks)	
Assessment	50 MCQ	
Post course assessment	20 MCQ	20 MCQ
Total course duration	2.5 days	3.0 days

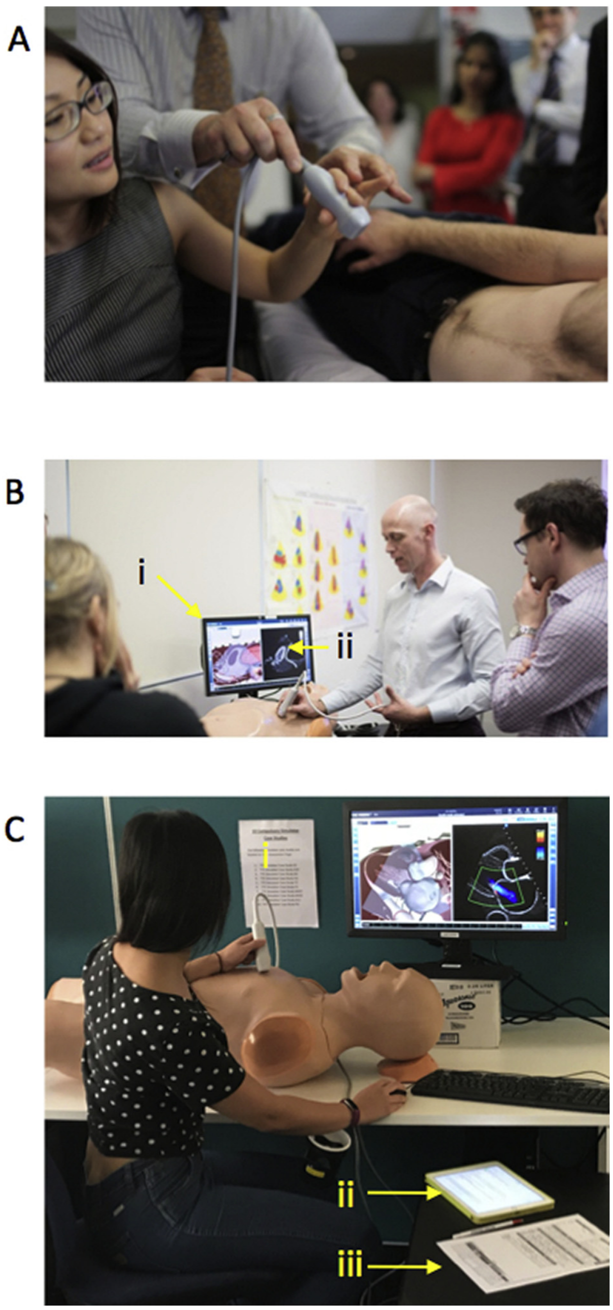

Fig. 1. Human and simulator model focused cardiac ultrasound courses. A - The human model course (iHeartScan™, University of Melbourne) practical training was provided in the form a 1.5 day workshop of supervised instruction of focused cardiac ultrasound using echocardiography on healthy human volunteers with a maximum ratio of 1 instructor per 5 participants. The simulator model course (Focused Cardiac Ultrasound Transthoracic Echocardiography, University of Melbourne) practical training was provided in two parts: (B) A quarter-day supervised instruction of focused cardiac ultrasound using a Vimedix™ ultrasound simulator with a maximum ratio of 1 instructor per 5 participants. The simulator enhances learning of sono-anatomy by simultaneous display of both anatomy (i) and ultrasound (ii). (C) Unsupervised practice of 10 pathology cases loaded on the simulator by entering codes (i) over a four-week period on the simulator guided by internet instructions via a personal digital device (ii). Reporting of the simulated pathology cases was performed using a report form (iii) and assessment was via 5 on-line multiple choice questions that were automatically marked and answers and feedback provided to the participant in real time.

pathology on a simulator. In the case moderated sessions with the instructor, the participants are asked to view the ultrasound images and perform a written report, which is then reviewed by the instructor and participants in a group verbal discussion, where feedback is given verbally rather than via electronic MCQs.

Prior to practical learning for both courses, the baseline interpretive skill was assessed using a supervised exam of 20 MCQs. The exam was designed to assess knowledge of image acquisition and interpretation of FCU and included both pictorial and non-pictorial questions, however there were no moving images included in the exam. Participants also completed an anonymous survey of age, gender, level of medical training and experience and training with FoCUS, to identify whether the groups had equivalent prior FCU training.

2.1. Learning outcomes

Learning outcomes were assessed after the practical training, which included a 20 MCQ exam to assess FCU knowledge and an image acquisition test on healthy human models. Three months after course completion, participants were contacted and requested to complete the third 20 MCQ knowledge test and a course satisfaction survey. The knowledge base MCQ's are therefore performed i) immediately prior to the practical training workshop (baseline), ii) immediately after the practical training, and iii) at three months after course completion, along with the survey. The image acquisition test is performed after the practical training. The three MCQ tests and pre- and post-course surveys shown in Supplementary digital material 1.

2.2. Primary outcome: normalized image acquisition score

The image acquisition test was designed to assess the ability of participants to obtain 10 standard FCU views using the parasternal, apical, and subcostal windows on healthy human volunteers using a portable echocardiography machine (X-porte, Sonosite, Bothwell, Andover, MA, USA). Each participant was requested by a FCU instructor to sequentially obtain his or her best possible attempt at acquiring each FCU view within a 14-min time limit. For participants in the iHeartScan™ course, the image acquisition test was performed as the last part of the workshop, whereas the simulator participants were recalled approximately 1 month after completion of the initial training workshop, in order to allow completion of the simulator practice. The digital images were stored for subsequent off-line analysis using a previously published image quality assessment tool [9] by two independent operators, suitably trained and certified in FCU, who were blinded to the participant's group and to each other's assessment. The image acquisition test has been previously validated to allow discrimination between differing levels of FCU competence and is shown in Supplementary digital material 2. Each view comprises between one and 10 binary assessment questions. The assessment questions were devised by two authors (DC and CR), which assess adequate visualization of cardiac structures; axis alignment, absence of foreshortening of the left ventricle or ascending aorta; positioning the region of interest in the center of the sector; and at a suitable sector depth. The views included the parasternal long axis view (10 points), right ventricular inflow view (4 points), parasternal short-axis view at the level of the aortic valve (7 points) and the mid LV (8 points), apical four-chamber view (9 points), apical five-chamber view (1 point), apical two-chamberview (8 points), apical long-axis view (9 points), subcostal four-chamber view (8 points), and the subcostal inferior vena cava view (4 points).

For each set of human models, two experts scanned the models and the average of their image quality scores represented the “best possible score” for each view. The normalized image quality score is the participant's score / experts score as a percentage.

2.2.1. Secondary outcomes

Three 20 MCQ exams (pre-practical training, post practical training, and 3 months after course completion) were conducted to assess interpretive ability as well as a participant satisfaction survey. The satisfaction survey was an anonymous questionnaire about their learning experience with either simulators or human models. The survey contained six questions, using a five-point Likert scale (strongly agree, agree, neutral, disagree, strongly disagree).

A cost analysis was performed comparing the direct costs associated with the ultrasound training for both groups, and were the actual costs incurred by the University of Melbourne for either course, including administrator time. These costs did not include the cost of instructor time as all instructors volunteered their time. Instructor and participant time to provide the instruction or to complete the program were expressed in number of days.

2.3. Statistical analysis

We pre-specified (a priori) an absolute difference between groups to define that the simulator was not worse than the human model group of 5% for mean normalized image acquisition scores, which we considered to represent a significant difference in scores. A two-tailed design was included to consider potential superiority of the simulator course. Using an independent samples *t*-test approach, alpha at 0.05 and power at 0.9, 55 participants were required in each group. We increased the number potential participants to 80 in each course type, to account for potential non-inclusion non-completion.

Continuous data are presented as mean and 95% confidence intervals, and compared using independent samples Students t-test. Categorical variables are presented as n (%) or median, range and interquartile range where appropriate and compared using Chi squared test. Significance for the primary outcome is defined as $P < .05$. but to reduce the risk of type I statistical error, significance for secondary outcomes is defined as $P < .01$.

Interobserver variability was assessed for image quality scores by two observers by measuring the mean and standard deviation of the difference. Limits of agreement are defined as ± 2 SD of the difference. Agreement between observers was considered to be acceptable if the limits of agreement were <30% of the mean value of the variable being measured.

3. Results

Between March 1st 2015 and 18th[th] January 2017 a convenience sample of 161 participants were enrolled into the education programs (80 participants in the human model group and 81 participants in the simulator group), who all completed their eLearning. After the eLearning and prior to practical training, 11 participants in simulator group and 6 participants in the traditional group either declined participation in the study or were excluded as they were not able to present for follow up (Table 2). Of these participants, 13 participants in the simulator group did not complete the post-course knowledge or practical image acquisition test, and 13 participants in the simulator group and 22 participants in the traditional group did not complete the 3-month post course knowledge test or satisfaction survey.

Table 2
Enrolment and completion of study of simulator and human model course participants.

Variable	Simulator n	Human model n
Enrolled in the courses	80	81
Consented to the study	70	75
Completed course	70	75
Completed post-course knowledge assessment	57	75
Completed post-course image acquisition test	57	75
Completed 3-month post-course knowledge assessment and satisfaction survey	44	43

3.1. Baseline participant level of medical and FCU training

There were no differences between the simulator and human model groups in either gender (59% male vs. 53%, $P = .164$) or previous training in echocardiography (40% vs. 33 % ,$P = .964$). The median age (median {IQR < range>}) of the participants was lower in the simulator group (34 yr {30 to 39 < 24 to 55>}) compared to the traditional group (37 yr {33 to 45 < 21 to 62>}, ($P = .001$)). The proportion of specialist attending physicians was also lower than in the simulator group compared to the traditional group (24% vs. 58%, $P = .004$). Despite the differences in age and medical seniority, the pre-practical training knowledge scores were similar between groups (78.6%, 75.7–81.5% vs. 79.0%, 76.4–81.6%, $P = .842$), indicating equivalent FCU knowledge after the eLearning but prior to the practical training.

3.1.1. Primary endpoint

Q-Q plots of the image quality, knowledge and satisfaction scores indicated that the assumption of normality was satisfied. After the practical training, the normalized image quality scores (mean, 95%CI) were superior in the simulator group compared to the traditional group (95.2%, 91.3–99.1% vs. 66.0%, 61.7–70.3%, $P < .0001$) and are summarized in Table 3. The normalized image quality score for each of the 10 FCU views was superior in the simulator group. The view with the greatest difference in score between groups was the subcostal inferior vena cava view (101.2%, 92.8–109.6% vs. 50.3%, 41.3–59.3%, $P < .001$) and the view with the least difference in score between groups was the parasternal long axis view (98.9%, 95.0–102.8% vs. 85.5%, 80.5–90.5%, $P < .001$).

3.1.2. Secondary endpoints

The interpretive knowledge scores are shown in Table 4. Scores were not different both after the practical training (74.7%, 71.6–77.7% vs. 76.1%, 73.3–78.9%, $P = .495$) and three-months after course completion (81.0%, 76.1–85.9% vs. 77.0%, 73.1–80.9%, $P = .197$). Including the cost of one simulator (simulator group) or 5 ultrasound machines (human model group), the sum of direct costs (per participant) was lower for the simulator course than the human model course ($796 vs. $1724).

The time invested for course administration was lower in the simulator course (1 day vs. 8.4 days), which was included in the direct costs (as shown in Table 5). The time invested for the whole course was lower for both instructors (0.5 days vs. 1.5 days) and participants (2.5 days vs. 3.0 days) for the simulator course. Time invested in practical training was comparable (1.25 day vs. 1.5 days), however in the simulator group this time was spread out over 4 weeks compared to 1.5 days for the traditional group, who attended a 1.5-day workshop for their practical training. Satisfaction with both programs (agree or strongly agree) was very high and not different between groups (95% vs. 93%, $P = 1.0$).

The interobserver variability showed acceptable agreement for the image quality scores, with the limits of agreement of 15.6% of the mean scores Fig. 2.

4. Discussion

This study has demonstrated that the simulator based learning program is non-inferior to the traditional workshop style teaching program utilizing human models for interpretive knowledge and satisfaction, and is superior for image acquisition skills.

The non-inferiority design was used as we were concerned that learning to acquire images on a simulator may not provide equivalent training to acquiring images on humans, as is taught in the traditional course, and as reported in the expert consensus recommendations by the American Society of Echocardiography [15]. Both courses delivered identical knowledge base teaching (eLearning) so it is unsurprising that the learning of interpretive skills was similar. Both courses provide interpretive learning additional to the pre-workshop eLearning. In the traditional course, instructors moderate case discussions of pathology

Table 3
Comparison of post-course normalized image acquisition test scores between simulator and human model courses. Values are mean (95% confidence intervals).

	Normalized image quality score Mean score (95% confidence intervals) %		P
	Simulator group	Traditional group	
Total normalized image quality score	95.2 (91.3–99.1)	66.0 (61.7–70.3)	<0.001
Normalized image quality score per view			
Parasternal long axis view	98.9 (95.0–102.8)	85.5 (80.5–90.5)	<0.001
Right ventricular inflow view	107.1 (97.7–116.5)	64.6 (55.2–74.0)	<0.001
Parasternal short axis view – aortic valve level	100.9 (96.5–105.3)	81.1 (74.8–87.4)	<0.001
Parasternal short axis view – mid left ventricular level	98.7 (93.8–103.6)	76.6 (71.5–81.7)	<0.001
Apical four-chamber view	96.5 (92.2–100.8)	63.4 (57.2–69.6)	<0.001
Apical five-chamber view	103.8 (93.8–113.8)	76.4 (61.4–91.4)	0.008
Apical two-chamber view	82.0 (71.0–93.0)	52.4 (41.4–63.4)	<0.001
Apical long axis view	89.2 (80.1–98.3)	47.6 (36.6–58.6)	<0.001
Subcostal four-chamber view	103.4 (92.4–114.4)	71.4 (58.4–84.4)	<0.001
Subcostal short axis view – mid LV level	90.3 (70.3–110.3)	49.9 (38.9–60.9)	<0.001
Subcostal inferior vena cava view	101.2 (92.8 to 109.6)	50.3 (41.3–59.3)	<0.001

displayed to a group of participants, who practice interpretation and reporting. In the simulator course, participants acquire and interpret images of pathology on the simulator and submit and receive feedback on MCQ questions and receive case summaries that contain additional teaching of interpretation of pathology. Both of these styles of teaching are likely to be effective for knowledge interpretation as both include clinically relevant pathology case reviews that are interactive and engaging, with some form of self-assessment (either peer-review or MCQ).

It was surprising that the image acquisition skills of the simulator group participants were superior as, unlike the traditional group, they did not receive training or experience in ultrasound on humans. Neelankavil et al. [3] reported improved FCU image acquisition in participants taught with a simulator compared with didactic teaching. However, both groups received FCU training in the traditional style of supervised scanning of healthy human volunteers, and hence the addition of simulator training did not help with ability to scale training. To our knowledge, our report is the only one that tests learning with a simulator in a self-directed manner, and without scanning practice on healthy human volunteers. A likely mechanism is that the simulator practice was in an environment protected from distraction of a busy and noisy workshop environment, providing an atmosphere more conducive to learning. Another likely mechanism is the simulator practice represents spaced learning, where the learning is repeated at time intervals over the four-week time period, compared a single burst of learning of 1 and a half days provided by the workshop. It is likely that unless one practices on patients or volunteers after the workshop, the image acquisition skills are likely to rapidly fade. Spaced education using repeated emails of MCQs has been shown to improve efficiency in medical education [16,17], and has had popular feedback from participants, especially when delivered as a game that introduces competition between participants [17].

Another potential benefit with the simulator is the ability to "game", where the participants use the three-dimensional rendered anatomy imaging to help align the probe movements with the TTE images. Another potential advantage of ultrasound simulators is in the learning of cardiac anatomy. Canty et al. [18] reported similar knowledge base scores in cardiac anatomy between participants randomized to self-directed learning with either an ultrasound simulator (FCU not TEE) or labeled human cadaveric specimens. Although the overall knowledge scores were not different, the knowledge scores were higher in the simulator group for the pictorial questions, indicating a potential advantage in learning the 3-dimensional spatial anatomy with the simulator. Ogilvie et al. [19] demonstrated improved knowledge base learning of cardiac anatomy in participants randomized to receive learning with a transesophageal echocardiography simulator compared to learning with transesophageal echocardiography in anesthetized patients. If the simulators provide superior learning in sono-anatomy then this could translate into superior learning of image acquisition.

The ability to scale a learning program relates to direct cost as well as time cost for the instructors and participants. The 1.5-day workshop is an event, which requires a venue, catering and transport and accommodation of instructors and administrative staff and human volunteer models. The self-directed learning of the simulator course meant that only three hours of instructor time was required per five participants, which was conducted during office hours during the normal rostered hours of the trainers. At current market value an ultrasound simulator capable of teaching FCU is $150,000, with an arbitrary lifespan of 10 years equates to an annual cost of $15,000 per year, and $422 per participant. This is less cost ($736 per participant) than the purchase of the 5 ultrasound machines required to teach 25 participants at a time in the human model course. However, it is possible that a department may be able to borrow enough ultrasound machines from the hospital for use in the human model course. Even then, the simulator course would still be cheaper to run than the human model course ($796 vs. $988).

The principal advantage of the simulator course for initial training in FCU is that is offers a more scalable solution to training, which is primarily due to a four-fold reduction in required instructor time. This has the direct impact on ability to scale, as the instructors are typically attending anesthesiologists or other physicians whose primary role is patient care, and they cannot afford large commitments of time to teach on workshops.

Limitations of this study include the observational nature of the design, which was aimed at establishing proof of concept rather than outcome. A randomized study would have been preferable but this was not feasible as recruitment occurred after enrollment into the specific courses. As there was a significant attrition in follow up of image quality

Table 4
Interpretive test scores of simulator and human model course participants. Values are mean (95% confidence intervals).

MCQ score	n	Simulator group % (95% confidence intervals)	n	Traditional group % (95% confidence intervals)	P
Pre-practical training	70	78.6 (75.7–81.5)	75	79.0 (76.4–81.6)	0.842
Post-practical training	57	74.7 (71.6–77.7)	75	76.1 (73.3–78.9)	0.495
Three-month post-course	44	81.0 (76.1–85.9)	43	77.0 (73.1–80.9)	0.197

Table 5
Comparison of direct costs of the simulator and human model focused cardiac ultrasound courses. Values are Australian dollars.

Costs	Simulator		Human model	
	Notes	Cost per participant ($)	Notes	Cost per participant ($)
Equipment	1 x Ultrasound Simulator[1] Warranty for simulator[2]	$297 $125	5 x Ultrasound machines[3] Warranty for ultrasound[4] Massage bed hire[5] (for human volunteers)	$509 $227 $13
Pre-workshop eLearning – 5 on-line tutorials and 20 FCU cases	All on-line and automated marking	250		250
Workshop – venue hire, catering	Venue hire, no catering	10	Venue hire and catering	329
Post-practical training practice	Venue hire for simulators for 4 weeks	59	Not required	–
Human models	Not required	–	$100 per model per day[6] (2 days)	37
Stationary	3 x A4 pages	1	Booklet	7
Instructor – flights, accommodation, parking or taxi, meals		4		272
Administrator		50		80
Total Direct Costs		$796		$1724

[1] Cost of an ultrasound simulator (Vimedix, CAE Healthcare, Montreal, Canada) is $158,370, which is depreciated over 10 years at $15,837 per year. The study period was 1.5 years equating to a total cost of $23,756 for the study, costing $339 per participant (n = 80).
[2] Warranty cost is $6678 per simulator per year (0.044% of cost price), equating to a total cost of $10,017 for the study, and $125 per participant (n = 80).
[3] Cost of an ultrasound machine (X-porte, Sonosite, Bothwell, Andover, MA, USA) is $55,000. One machine is required per 5 participants per course. There was an average of 25 participants at each of the 3 courses, there 5 machines were required, costing $275,000 depreciated over 10 years equating to a total cost of $27,500 per year equalling $41,250 for the study (1.5 years), costing $509 per participant (n = 81).
[4] Warranty cost is $2449 per ultrasound machine per year ($12,245 for 5 machines), equating to a total cost of $18,364 for the study (1.5 years), and $227per participant (n = 81).
[5] Massage bed hire $72 per bed, 5 beds per course ($360) for 3 courses ($1080), costing $13 per participant (n = 81).
[6] Five models were paid $200 for each of the 3 courses costing a total of $3000 for the study, costing $37 per participant (n = 81).

assessment of the simulator group compared with the traditional group, and therefore there is potential for attrition bias, where the participants who may have been more committed to learning may have been more likely to represent for follow up, which could have skewed the results in favor of the simulator group. However, this may be balanced out by the decreased level of medical experience in the simulator group. Although ultrasound simulators are a valuable tool in learning to perform and interpret FCU, they have limitations, which include inability to simulate the wide range of patient body habitus, chest wall structure, translational motion of the heart due to respiration, heart orientation within the chest, cardiac size, patient cooperation, and normal variants. The expert consensus statement on FCU from the American Society of Echocardiography recommends that 'although ultrasound simulators may be used as an adjunct in FCU training, the majority of hands-on studies should be performed on human subjects' [15]. Although the simulator group participants outperformed the human model group in

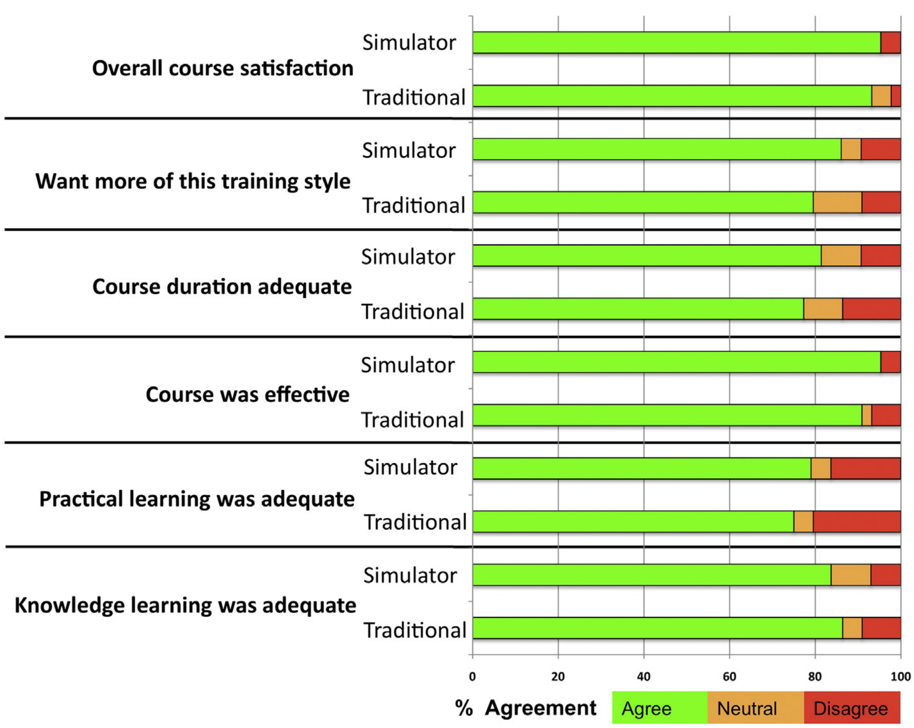

Fig. 2. Satisfaction survey results of the simulator and human model participants. Answers were collapsed for the sake of clarity from a five point Likert scale (Strongly agree, + agree = agree, neutral, disagree+ strongly disagree = disagree).

performing FCU on healthy human volunteers a comparison cannot be made on ability of the two groups in ability to scan patients. Hence practice on patients should be factored into any FCU teaching program and how to incorporate scanning of patients into an FCU program without loss of scalability remains as an important research question to answer.

5. Conclusion

Interpretive learning outcomes were non-inferior, but image acquisition was superior for self-directed simulator learning of focused cardiac ultrasound compared with supervised human model workshop course. Direct costs, instructor and training time were lower for the simulator course

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Conflict of interest statement

Colin Royse, Alistair Royse and David Canty are employees of the University of Melbourne, and Colin Royse and Alistair Royse are directors of iTeachU limited. Educational content from these entities are available for sale in the United States of America through the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiology. The University of Melbourne has received loan equipment from the simulator company CAE.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrc.2018.10.006.

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